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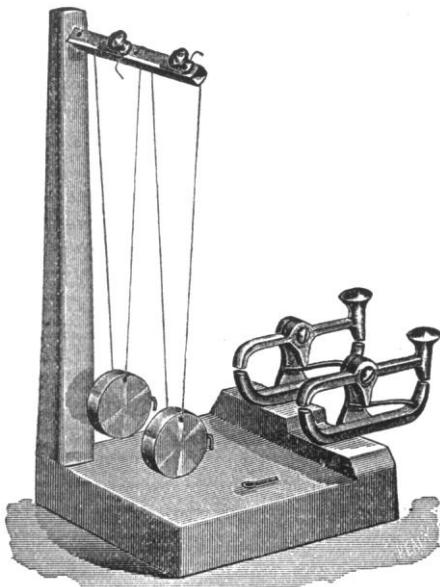
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THE VERNIER CHRONOSCOPE.

By E. C. SANFORD.

Some years ago, the writer described a simple chronoscope on the principle of the vernier, capable of measuring short intervals of time in hundredths of a second.* The instrument was crude, and probably has never been put to serious use, but the need of a number of time instruments of some sort for a brief practice course at the Clark Summer School of 1897 led to a second attempt and finally to the instrument pictured and described below, which has proved itself very satisfactory in actual use and won commendation from several who have seen it.



The essential part of the instrument is the pair of unequal pendulums at the left. The longer of these is of such a

* This JOURNAL, III, 1890-91, 174. The idea was borrowed from the astronomer Kaiser, who used it more than forty years ago in studying "personal equation."

length as to make one complete swing (*i. e.*, to traverse its arc and return to the same point) in 0.80 seconds; the shorter makes a complete swing in 0.78 seconds, thus gaining 0.02 seconds at each of its swings, and fixing the unit of measurement of the instrument at one-fiftieth of a second. With these rates, if both pendulums start together, the shorter will gain a whole swing of the longer, and they will be together again after forty of its swings; $0.80 \div 0.02 = 40$. If the shorter starts later than the longer, it will gain as before at the rate of one-fiftieth of a second per swing; and in order to know in fiftieths of a second the interval by which it started later, it will only be necessary to count its swings until it catches up; and in general to measure any short interval, it will only be necessary to start the longer pendulum at the beginning and the shorter at the end, and to count the swings of the shorter up to and including a coincidence. The number counted is the interval expressed in the units of gain, that is, in fiftieths of a second.

The counting of the shorter corresponds to the common usage in counting a vernier, but in this instrument the counting of the longer pendulum is from its position somewhat easier, and as the number of swings is the same in either case, no error is introduced by so doing. In the remainder of the description it is assumed that the count is made upon the longer.

In measuring intervals of over 0.80 seconds, the long pendulum will complete one or more swings before the short pendulum starts. When this happens a difference must be made in the counting. For each whole swing made by the long pendulum, *before the short one starts*, forty units must be added to the value given by the count while both are in motion. Suppose, for example, that the long pendulum has made one swing before the short one starts, and that six more swings are made before the coincidence, the total time would be $40 + 6$ units of the instrument, or 0.92 seconds, in the perfectly adjusted instrument. If the long pendulum should make three whole swings before the shorter starts and then twenty more swings to the coincidence, the time would be $3 \times 40 + 20 = 140$ units of the instrument, or 2.8 seconds. With a little care the measurements of these longer times need offer no difficulty.

How the adjustments of the pendulums are made will be explained after the construction of the instrument has been described.

The Construction of the Chronoscope.

The base of the instrument is of cast iron ($4\frac{3}{8}$ inches long,

4 inches wide and $\frac{7}{8}$ of an inch thick). On one corner of it rises a column ($7\frac{1}{2}$ inches high, above the base) which, with the little platforms supporting the keys, is cast in one piece with the base.

From the top of the column an arm extends forward over the base $3\frac{1}{2}$ inches. This is made of quarter-inch square brass rod and is set cornering so as to allow the threads of the pendulums to hang from an edge. One end of each thread is tied fast through a hole in the arm, and the other is clamped under the head of the corresponding screw on the upper side of the arm, thus providing an easy adjustment in length. Both the tied and the clamped ends pass up over the upper edge of the arm and down on the right side, where they lie in four narrow file cuts to prevent them from slipping laterally and thus altering the length of the pendulums. This is a slight feature in the construction, but important for accuracy. The threads are ordinary silk butt n-hole twist, red for the long pendulum and blue for the short. The bobs are brass disks a little over an inch in diameter and three-eighths of an inch thick. The length of the longer pendulum is approximately $6\frac{1}{8}$ inches, from the edge of the arm to the center of the bob; that of the shorter, approximately $5\frac{7}{8}$ inches.

The pendulums are released from the keys at the right in the cut. Each of these catches between its lips, represented as half open, a little loop of wire like that lying upon the base, and into the loop is dropped the hook on the side of the bob. When the knobs of the keys are depressed, the loops are released and the pendulums start. The structure of the keys is very simple. The upper bar turns on the screw as a pivot, and is held in either the closed or open position by the spring, which acts upon the downward projecting cam.* A round brass post extends downward from the under side of the lower bar, fitting into a hole of the same size in the base, and is held in place by a set-screw not shown in the cut. This arrangement provides a vertical adjustment of the keys, by which they are easily brought into the right relation to the pendulum.

The instrument in this form can be used for reactions with auditory or tactful stimuli; for use with visual stimuli, a small addition is required which is described below, in connection with the method of using the instrument for reactions to visual stimuli.

* This plan was suggested by Prof. Jastrow's reaction key, this JOURNAL, Vol. IV, 1891-92, p. 210.

Adjustment and Control of the Instrument.

The adjustment and control are as simple as the construction. The long pendulum must first be brought, by varying its length, to swing in 0.80 seconds, that is, 150 swings in two minutes. If the timing is done with a stop watch, this is easy for a single observer; if with an ordinary watch, it is a little more convenient to have the time kept by one observer and the count by another. The pendulum is started; observer A taps upon the table for the beginning of the two minutes; observer B begins the count, calling the first count "naught," and continues till A taps for the end of the two minutes. The pendulum is then lengthened or shortened, as the count indicates. It would be a long process to get the adjustment so exact as to give just 150 swings, but that is not necessary. It is better to accept an approximate adjustment (e. g., 149 or 151), and to apply an arithmetical correction later if necessary. The short pendulum is better regulated by the long one than directly by the watch. Both pendulums are set swinging, and the count started at a coincidence (called "naught") and the counting continued till the pendulums are exactly together again, which should happen at the end of the thirty-ninth swing of the longer. As before, an approximate adjustment is sufficient.

Adjustment in the last case is a somewhat more delicate matter than before, and if time is short, one which brings a coincidence at the thirty-seventh or forty-first swing will serve. It is more important to know the exact swing upon which the coincidence occurs than it is to make it occur upon a particular one. If greater accuracy than can be reached by a single count is desired, the counting may be continued through two or more periods. An adjustment giving a coincidence at $39\frac{1}{2}$ swings, for example, would show the second coincidence at 79, the third at 118.5, and so on.

The adjustments can be made more rapidly than might be inferred from this description of them, and once made require no more than an occasional counting to make sure that they have not changed.

The arithmetical correction above mentioned is easy to obtain. Suppose, for example, that the long pendulum is found to swing 148 times in two minutes and that coincidences occur every 37 swings. This will mean that the time of a single swing of the long pendulum is 0.81 seconds, and that the short pendulum makes 38 swings to 37 of the long.

The unit of the instrument is then 0.0213 ($0.81 \div 38 = 0.0213$), instead of 0.02 , as it would be if exactly adjusted. In this case the final records would be reduced to hundredths of a second by multiplying by 2.13 instead of by 2 . For many demonstrational purposes no correction at all is necessary, all records being kept directly in the units of the instrument.

Methods of Using the Instrument.

For simple reactions to auditory stimuli, the method of operation is as follows: The subject and operator being in place (the latter with closed eyes) and the pendulums hooked into the loops, the operator gives a "ready signal," and a second or two later taps his key smartly with the back of a pocket knife or other convenient bit of metal. The tap releases the long pendulum, at the same time producing the sound to which the subject reacts by pressing his key; the operator counts the swings of the long pendulum till the two are in coincidence, and the number is the reaction-time in the units of the instrument.

Sometimes the coincidence seems equally good on two swings. This indicates that the real coincidence fell between them, and the record is to be made accordingly. If it has seemed to occur on both the 10th and 11th swings, the record is 10.5 swings. For this reason it is well not to cease counting at the first sign of coincidence, but to continue till separation is evident, noticing, of course, to which swing, or swings, the coincidence really belongs. The counting and the judging of coincidences require a minimum of practice, but the knack is very soon acquired.

For reactions to visual stimuli, two small changes in the apparatus are needed. A screen must be set up between the subject and operator, and an arm attached to the operator's key for presenting the visual stimuli at the instant of the release of the pendulum. For holding the screen, a vertical saw-cut has been made in the base of the instrument, half way between the keys and extending an inch or more toward the center. A stiff piece of cardboard a foot or so square set into this cut will stand of itself and furnish all the screen necessary. (The cut is unfortunately not shown in the illustration above.) The arm for carrying the visual stimuli is a vertical brass rod, about five inches long, screwed into the operator's key just above the pivot. At its upper end, this rod carries a spring clip, into which are set the bits of black, white, or colored cardboard, about an inch square, which serve for the visual stimuli. When the knob of the key is depressed, the rod is thrown to the right and

the stimulus card brought before a suitable opening in the screen. The movement at the top of the rod is only about half an inch, but this is sufficient for most purposes. Since the pendulum is released the instant the depression of the knob begins, the opening must be rightly placed and the edge of the stimulus card must lie as near to it as possible. To facilitate this the card is also brought as close as possible to the screen by giving the rod a double bend toward the other key. The noise produced by the striking together of the right ends of the bars of the key when the key is suddenly opened is a disadvantage in visual experiments, and may be obviated by slipping over both (as if to connect them) a half-inch bit of quarter-inch rubber tubing, in the middle of which a little cotton has been placed. The noise may be very much diminished in this way without too great reduction in the movement of the upper end of the arm.

Reactions to touch, or more exactly to pressure, may be tried by having the subject place one fore-finger under that of the operator on the operator's key. He will thus receive a pressure in it at the instant that the operator's pendulum is released and can release his own pendulum with the other finger.

Reactions involving discrimination and choice, in Dunder's form (*i. e.*, by reacting to only one of two or more stimuli and refraining from reaction to the rest), can easily be tried with the chronoscope arranged for visual stimuli. The number associations (adding, subtracting, multiplying, dividing, squaring, etc., etc.) can also be tried with the same arrangement, if the problem is given in such a way that the subject cannot begin to solve it till he is shown a digit through the hole in the screen. For example, the subject is told to add to 17, a number to be shown. As soon as the operator's key is depressed, he sees the digit required and begins his adding, pressing his key and announcing the result simultaneously when he has reached it.*

With experiments in an auditory form, the range of application is still wider, any sort of association time being measurable when the operator makes the depression of his key coincide with the calling of the stimulus word, and the sub-

* It might seem sufficient for the subject to press his key without calling out the result, but there is probably less tendency to anticipatory reactions when vocalization is required, and the subject is in a better position to report upon his success in making the depression of the key coincide with the termination of the mental task.

ject makes the depression of his coincide with his response.*

The following points in regard to the management of the chronoscope should be regarded. In preparing the instrument for use the operator should see that the keys are so set as to release the bobs with as little independent motion as possible, and that the bobs hang straight in the middle of their threads when at rest. The keys should catch the wire loops at such a point as to bring the threads of both pendulums approximately into the same plane. It is easier to judge the coincidences by sighting across the threads than by watching the bobs. The bobs show a tendency to wear the threads unless the holes in them are carefully smoothed, which probably could be prevented by waxing that part of the thread. It will be found convenient, though by no means necessary, to clamp the instrument to the table on which it is used to prevent the subject from displacing it by over-vigorous reacting.

The instrument can easily be given a form in which the bobs are released from electro-magnets, and one of that sort is now in the Clark laboratory. Such an arrangement, however, introduces not only the time error of the magnets—a small matter probably in any use to which such an instrument would be put—but also requires additional keys, batteries and subsidiary apparatus, which would multiply the cost beyond reason. The instrument has been spoken of as a demonstrational instrument, and such is its primary purpose, but it is evidently capable of serving for research in any case where a unit of one-fiftieth of a second is sufficiently small.

* For valuable suggestions, both as to construction and methods of use, the writer is indebted to Prof. E. B. Titchener, in whose "Primer of Psychology," the instrument and experiments are also described.